Lifetime of the Superallowed Beta Decay of ^{14}O

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We have measured the lifetime of the superallowed beta decay of ^{14}O. Measurements of the decay rates of superallowed (0+ $\rightarrow$ 0+) transitions determine the V_{ud} element of the Cabbibo-Kobayashi-Maskawa (CKM) matrix.[1] The CKM matrix parametrizes the mixing of quarks from their mass eigenstates to the eigenstates which participate in the Weak Interaction. This transformation matrix is unitary in the Standard Model, and non-unitarity would imply new physics such as extra generations of quarks or leptoquarks. The V_{ud} element dominates the unitarity test of the first row and is studied by precise measurements on pure vector beta decays, in which the nuclear matrix elements may be calculated by isospin symmetry. Isospin breaking corrections are small in low-Z nuclei, and ^{14}O is a favorable candidate for study, since the superallowed decay branching ratio is > 99%, and the lifetime ($t_{1/2}$=70.6 sec.) is convenient for counting experiments.

We produced ^{14}O at the 88-Inch Cyclotron using a ^{3}He beam on a carbon aerogel target. The ^{14}O combines chemically with the carbon to form C^{14}O gas, which is then pumped into an electron-cyclotron-resonance (ECR) ion source. This ISOL technique results in an extremely pure beam of ionized ^{14}O at roughly 30 keV. The ^{14}O ion beam was implanted in a thin foil, and the foil was shuttled to a thin-walled counting cell surrounded by heavy shielding

Previous measurements of the half-life of ^{14}O counted the 2.3 MeV gamma ray emitted in 99% of the ^{14}O decays. The response of a high-resolution gamma-ray detector is slow, and we chose to take advantage of the high purity of our radioactive ion beam and detect the positrons emitted by ^{14}O with fast, thin plastic scintillators. This allowed counting many decays in a reasonable acquisition time. Using four detectors placed near the counting cell, we counted the implanted ^{14}O sample as a function of time for more than 50 half-lives (4000 seconds). The long counting time was important to establish not only the level of the constant background rate in each detector, but also to search for long-lived contaminant species, ^{11}C ($t_{1/2}$ = 20 min), ^{13}N ($t_{1/2}$ = 10 min), and ^{15}O ($t_{1/2}$ = 122 sec.). The contaminants were produced in the target and transported as gas to the ECR source.

We took roughly 27 cycles of data during April 2002, representing 10^9 total counts of ^{14}O decay. We used a maximum likelihood fitting technique, rather than a least-square (χ^2) minimization because of the well-known bias introduced by χ^2 minimization when fitting data with either low statistics (small number of counts per bin) or data with a large dynamic range (five orders of magnitude in our case). Data were fit as individual cycles, to search for run-to-run variations of the half-life result, and by binning all 27 runs (separately for each detector) to minimize fitting bias caused by low statistics and to search for the presence of extremely small amounts of contaminant decay activity (Fig. 1). We observed ^{11}C contamination at a level of 10^{-4} of the initial ^{14}O activity, ^{15}O contamination at a level of 10^{-3}, and ^{13}N contamination at $<10^{-5}$. These amounts are consistent with a population of neutral gas which passes through the ECR source and which is distributed throughout the volume of the vacuum system and trapped in the counting cell.

We searched for systematic error caused by rate-dependent gain shifts in the photomultiplier tubes, gain instability, thermal drifts, or electronic instability. Each detector signal was sent through three separate counting channels, with different hardware dead times, to search for errors associated with dead time correction. Monte-Carlo simulations of the counting electronics were used to estimate the systematic uncertainty associated with deadtime, missed contaminants, rate dependent gain shifts in the PMT's and binning and fitting bias.

The statistical uncertainty of the measurement is approximately 10 ms. The systematic uncertainty from sources identified so far is approximately 20 ms, and is dominated by rate dependent gain shifts in the PMT, voltage instability in the first-stage discriminators, and non-statistical fluctuations in the background rates.

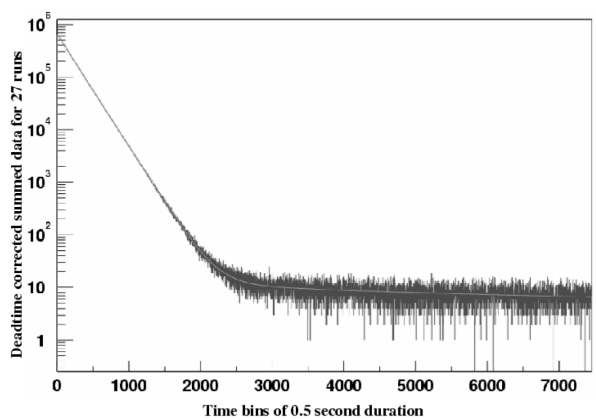

FIG. 1: Counts in one detector summed for 27 runs. The fit is shown as a thin grey line. The long-lived contaminant ^{11}C is apparent.

REFERENCES

[1] J.C. Hardy *et al*., Nucl. Phys. A 509, 429 (1990).